Validating the stock apportionment of commercial fisheries landings using positional data from Vessel Monitoring Systems (VMS)

Michael C. Palmer* and Susan E. Wigley

Northeast Fisheries Science Center, National Oceanic and Atmospheric Administration
166 Water St., Woods Hole, MA 02543-1026

*Corresponding author: tel 1.508.495.2041; fax 1.508.495.2393; e-mail michael.palmer@noaa.gov

Relevance to GARM Data Meeting: This paper addresses the uncertainty in statistical areas reported on Vessel Trip Reports (VTRs). VTRs are used to assign statistical and stock areas to commercial landings obtained from dealer weighout reports and therefore the accurate reporting of VTR statistical areas is a critical assumption of allocation algorithms (TOR item A. Commercial Landings).

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2006. Trip subcategories are based on the VMS-determined number of statistical areas fished.*Note: percentages may not sum to 100 due to rounding.*

Table 14. Frequency of trips fishing on multiple stocks based on VMS data from 2004 to 2006.

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Table 16. Results of the VMS-based stock area allocation compared to the stock area allocation based on the VTR reported statistical area for 2004. Relative difference is determined at % difference/VTR stock allocation; allocations ≥ 5.0 % relative differences are italicized. **Note: allocations may not sum to 100 due to rounding.*

Table 17. Results of the VMS-based stock area allocation compared to the stock area allocation based on the VTR-reported statistical area for 2005. Relative difference is determined at % difference/VTR stock allocation; allocations ≥ 5.0 % relative differences are italicized. **Note: allocations may not sum to 100 due to rounding.*

Table 18. Results of the VMS-based stock area allocation compared to the stock area allocation based on the VTR-reported statistical area for 2006. Relative difference is determined at % difference/VTR stock allocation; allocations ≥ 5.0 % relative differences are italicized. **Note: allocations may not sum to 100 due to rounding.*

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Abstract

Vessel Monitoring System (VMS) positional data from northeast United States fisheries were used to validate the statistical area fished and stock allocation of commercial landings derived from mandatory Vessel Trip Reports (VTRs). A gear-specific speed algorithm was applied to 2004 – 2006 VMS data from the otter trawl, scallop dredge, sink gillnet and benthic longline fisheries to estimate the location of fishing activity. Estimated fishing locations were used to allocate the landings of eight federally managed species to stock areas: Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), yellowtail flounder (*Limanda ferruginea*), winter flounder (*Pseudopleuronectes americanus*), windowpane flounder *(Scophthalmus aquosus*), goosefish (*Lophius americanus*), silver hake (*Merluccius bilinearis*) and red hake (*Urophycis chuss*). Haul location and catch data from the Northeast Fisheries Observer Program (NEFOP) were used to assess the relative accuracy of both VMS and VTR allocation methods.

Overall, the mean VMS – NEFOP agreement rate was 86.4 ± 7.6 % compared to a mean VTR – NEFOP agreement rate of 58.5 ± 4.9 %. The VMS algorithm had a tendency (approx. 10 % of all trips) to overestimate the number of statistical areas fish such that when all fishing activity from a given trip occurs in a single statistical area, VTRs more accurately reflected the true fishing location. However, on trips where fishing activity occurred in multiple statistical area, the VMS algorithm showed pronounced gains (77.2 ± 11.2 % NEFOP agreement) relative to VTR reports (12.0 ± 5.9 % NEFOP agreement). The VMS method achieved distributions of stock landings closer to NEFOP estimates in 18 out of 24 instances (8 species over 3 years). The stock allocations from both the VMS and VTR-based methods were within ± 5 % for all stocks, suggesting that the impacts on total stock allocations are relatively minor. However, these small differences represent major relative differences for less abundant stocks such as southern New England/mid-Atlantic yellowtail where in 2005 the VTR-based method allocated 61.9 % more landings relative to the VMS-based method. The VMS-based method is not a replacement for the VTR-based method; however, it can, and should, be used as a tool to identify those vessels where targeted outreach activities would improve the accuracy of VTR statistical area reporting.

Keywords: Vessel Monitoring Systems, Vessel Trip Reports, stock areas, allocation

Introduction

Among federally managed fish species in the northeast United States, eight species are managed and assessed as two or more discrete stocks. The eight species are: Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), yellowtail flounder (*Limanda ferruginea*), winter flounder (*Pseudopleuronectes americanus*), windowpane flounder *(Scophthalmus aquosus*), goosefish (*Lophius americanus*), silver hake (*Merluccius bilinearis*) and red hake (*Urophycis chuss*). Stock units are comprised of statistical area groupings (Fig. 1) with stocks defined by divisions that in most cases, relate to oceanographic features (e.g., Gulf of Maine, Georges Bank, etc.) (Table 1). All of the species are managed under the Northeast Multispecies Fisheries Management Plan (NEFMC, 1985), with the exception of goosefish which is managed under the Monkfish Fisheries Management Plan (NEFMC, 1998).

In the northeast United States, dealer weighout data are assumed to be a census of commercial landings amounts; commercial landings are allocated to management stocks using the statistical areas fished reported on mandatory vessel trip reports (VTRs) (Wigely et al., 1998). Current VTR regulations (50 CFR §648.7) require submission of paper logbooks upon completion of each fishing trip documenting the total catch by species for each statistical area in which fishing occurs. Despite regulations, it is known that misreporting of statistical area occurs, most frequently in the form of underreporting the number of statistical areas fished when fishing occurs in more than one area (Palmer et al., 2007; A. Applegate and T. Nies, NEFMC, August 17, 2007, pers. comm.). While, underreporting of statistical areas does not necessarily translate to misclassification of commercial landings to stock areas, the potential exists and the entire magnitude of these effects on the allocation of commercial landings is unknown.

The most reliable source of fisheries-dependent catch and effort data in the region are available from the Northeast Fisheries Observer Program (NEFOP). However, because these data are limited in their coverage (e.g., < 5 % of all certain fisheries in a given year, Wigley et al., 2007) they cannot provide the synoptic coverage necessary to allocate commercial landings to stock area with any regularity. Vessel monitoring systems (VMS) in the northeast were first implemented for the limited-access scallop fisheries in 1998 (NEFMC, 1993); their use has increased over time (Fig. 2) and expanded to cover many fisheries (Table 2). Historically, larger off-shore vessels participating in the limited-access scallop and special-access groundfish fisheries were more likely to be equipped with VMS compared to the smaller near-shore vessels. With the passage of Framework 17 to the Atlantic sea scallop FMP (NEFMC, 2005) and Framework 42 to the Multispecies Fishery Management Plan (FMP) (NEFMC, 2006), VMS is now required for a greater proportion of the smaller near-shore scallop and groundfish fleets. While VMS does not provide census coverage of these fleets, it does provide census coverage of trips taken by those vessels equipped with VMS. Given the increasing use of VMS in the region, this represents a potential tool to conduct large-scale validation of the statistical areas reported on VTRs.

Vessel positions obtained from VMS have been used as a proxy for location of fishing effort in prior work (Deng et al., 2005; Murawski et al., 2005; Mills et al., 2007). Many VMS programs do not require the transmission of instantaneous vessels speeds; only a vessel position and a date and time stamp. This has recently changed in some fisheries (Mills et al. 2007), however most users of VMS data must infer vessel speed and course from averages calculated from successive reported positions. Northeast United States VMS regulations only require the transmission of date, time and position information. In the northeast United States VMS data are typically collected once per 30 min from vessels participating in the limited access scallop fishery and once per 60 min from vessels participating in the groundfish fishery (Table 2).

Past work has characterized all activity falling within specific ranges of average vessels speeds to be indicative of fishing activity (Deng et al., 2005; Murawski et al., 2005). The vessel speed method can achieve accuracy levels as great as 99 %, however it can also result in the incorrect classification of non-trawling activity (Mills et al., 2007) leading to an overestimation of fishing intensity. A more complex method utilizing both vessel speed and directionality has been attempted; however, this method did not improve the detection of fishing activity and reduced the inclusion of false positives only slightly (0.7 %) (Mills et al. 2007). When using the vessel-speed method, the amount of classification error is sensitive to the VMS polling rate, the speed ranges used to define fishing activity and the practices of the fishery under observation (e.g., how much overlap exists between the vessel-speed signals of fishing and non-fishing activity, how long are individual hauls, etc.). With the exception of Mills et al. (2007) much of the work so far published in the fisheries literature has utilized VMS data without a quantitative assessment of the classification error of fishing vs. non-fishing activity when the vessel-speed method is used. This paper assesses the ability of the VMS vessel-speed method to detect the statistical area fished and allocate fishery landings to stock area by comparing results to matching NEFOP trips. The method is then applied to assess VTR area reporting compliance and its impacts on the current VTR-based allocation method used in the northeast United States.

Data and Methods

Data sources

VTR logbook trip, gear and species catch data were extracted from the VTR database (VESLOG tables) for calendar years 2004 – 2006; prior to 2004 < 500 vessels were equipped with VMS units, thus limiting the scope of a VMS-based allocation (Fig. 2). The analytical datasets were post-processed to remove any overlapping trips (i.e., trips taken by the same vessel with a date of sail occurring before the date of landing of a previous trip). Overlaps occur because of VTR reporting and/or data entry errors. This process resulted in the removal of 1.2 %, 1.7 % and 1.9 % of the total reported VTR trips in 2004, 2005 and 2006 respectively. Of the remaining trips, only those trips where at least one of the eight study species were reported as retained catch were kept in the dataset (Atlantic cod, haddock, yellowtail flounder, winter flounder, windowpane flounder, monkfish, silver hake and red hake). Because the focus was on assessing the impact of statistical area misreporting on the proration of commercial landings, discards were not included in these analyses. All species weights were converted to live weight in kilograms (kg) using standard NEFSC conversion factors. The VTR dataset was further restricted to include only the four major gear types which catch these demersal species in the northeast United States: fish bottom otter trawl (OTF), scallop dredge (DRS), sink gillnet (GNS) and benthic longline (LLB). The VTR database field, CAREA (calculated area) was used as the basis for allocating VTR reported retained catch. On each logbook sheet, vessel operators must report both the average fishing location (latitude x longitude or loran bearings) and the statistical area fished (Fig. 1). If the statistical area corresponding to the point location is not in agreement, or not adjacent to the reported statistical area, the reported statistical area is used to populate CAREA, otherwise CAREA is populated using the statistical area corresponding to the fishing location. VTR species landings were then assigned to a stock area based on the statistical area fished (Table 1). The final VTR subsets used in this analysis contained approximately 32,000 to 33,000 trips in a given year (Table 3).

All available VMS data were extracted from the VMS database for each vessel and assigned to the appropriate VTR reported trips by matching on vessel and assigning all VMS point locations with dates between the date of sailing and date landed reported on the VTR to the respective trip. The average vessel speed was calculated by dividing the haversine distance (Sinnott, 1984) by the time difference between consecutive fixes. All positions were assigned to a NMFS statistical area (Fig. 1). Summaries of the number of matched trips by year are included in Table 3.

All NEFOP trips which could be matched to the list of VMS-VTR matched trips were extracted from the OBDBS database. Matches were established on the vessel, date of sailing and date landed as reported on the VTR; trips with multiple matches were removed from the analyses. For all matched trips the associated haul duration, statistical area fished, species and retained catch weights were also extracted; retained catch weights were converted to live weight in kilograms (kg) using standard NEFSC conversion factors. Summaries of the number of matches by year are included in Table 3.

Method development and application
Some analyses using northeast US VMS data have differentiated fishing activity from non-fishing activity by using only upper-speed bounds; < 3.5 knots for bottom trawl vessels (Murawski et al., 2005) and < 5.0 knots for scallop dredge vessels (Rago and McSherry, 2001). To our knowledge no attempt has been made to identify fishing activity from the VMS signals of fixed-gear vessels (i.e., sink gillnet, benthic longline). We attempted to improve vessel-speed classifications and extend the application to fixed-gear vessels through a combination of visual examination of the percent frequency distributions of VMS-derived average speeds, knowledge of fishing operations and observations from high-frequency polled GPS data.

Percent frequency distributions of VMS average vessel speed were plotted for all gear types (Fig. 3). These were then compared to percent frequency distributions of activity-specific (fishing vs. non-fishing) instantaneous vessel speeds from high-frequency polled GPS data (1 fix/10 seconds) collected from vessels involved in NMFS cooperative research projects (Fig. 4). These data sets included precise observations of the dates and times of fishing activity. Four trips taken by four separate vessels were analyzed; two groundfish bottom trawl trips and two scallop dredge trips. Individual vessel speed observations from all trips were combined by gear type and activity was classified activity as either ‘fishing’ or ‘other’. ‘Fishing’ was defined as the period from winch brake lock to winch brake release; presumably the period when the gear is actually in contact with the bottom. Unfortunately, these data were not available for fixed-gear vessels. It is assumed that fixed gears such as sink gillnet and benthic longline gear are likely to be fished in very specific and limited geographic areas on a given trip, thus it is unlikely fishing is occurring on multiple fish stocks on a single trip. If this assumption is true, these analyses will not be as sensitive to misclassification of fixed gear activity compared to mobile gear activity.

VMS-based bottom otter trawl activity exhibits a very pronounced bi-modal distribution of vessel speeds. It was assumed that the first mode (2.8 knots) represented fishing activity and the second mode (8.0 knots) was indicative of steaming activity. Fishing activity falls within a very narrow range from approximately 2.0 to 5.0 knots as evidenced by the distributions observed from the high-frequency GPS data. A fishing speed window of 2.0 knots < fishing activity < 4.0 knots was used. This window fits the high-frequency polled GPS well, correctly classifying 99.2 % of fishing activity. However, it also incorrectly categorizes 31.8 % of non-fishing activity as fishing activity (Fig. 4). It is expected, that a portion of the non-fishing activity falling inside the window of fishing speed represents activity associated with the hauling and setting of the gear, which suggests that the impact of false-positives may not be as great as the 31.8 % figure implies.

The VMS-based average-vessel-speed distribution of scallop dredge activity has a nearly tri-modal distribution (Fig. 3). Unlike bottom otter trawl speed distributions, there is a high percentage of activity close to 0.0 knots. This may be indicative of shucking activity when vessels drift, allowing the crew to shuck scallops and clear the deck. The primary mode (4.2 knots) was assumed to represent fishing activity and the 8.2 knot mode was assumed to represent steaming activity. Scallop dredge fishing activity occurs over a broader range compared to trawl activity, falling between approximately 2 to 7 knots as evidenced by the distributions observed from the high-frequency GPS data (Fig. 4). A fishing speed window of 2.5 knots < fishing activity < 6.0 knots was used. This window fit the high-frequency polled GPS well, correctly classifying 98.3 % of fishing activity; however, it incorrectly categorized 69.3 % of non-fishing activity.

Like scallop dredge activity, VMS-observed sink gillnet average speed distributions have a tri-modal distribution (Fig. 3). Based on knowledge of gillnet operations, the first mode (0.6 knots) was interpreted as representing the hauling of gillnet gear, the second mode (3.0 knots) as re-setting the nets and the third mode (8.2 knots) as steaming activity. Benthic longline average speed distributions have a bimodal distribution (Fig. 3). The first mode (0.8 knots) was interpreted as representing the hauling and setting of the longline gear and the second mode (10.0 knots) as steaming to and from the fishing grounds. For both sink gillnet and benthic longline gear, speed bounds of 0.1 < fishing activity < 1.3 were used.

Those VMS locations identified as representative of fishing activity were then used to determine the statistical areas in which fishing occurred. Statistical areas fished were compared across data sources to assess whether the statistical areas derived from VMS-defined fishing activity represented an improvement over VTR reported statistical areas relative to NEFOP data. Trips were broken into two categories: single subtrip trips (fishing occurs in only one statistical area per trip) and multi-subtrip trips (fishing occurs in more than one statistical area per trip). Because all stock boundaries are divided along statistical area boundaries, correct reporting of multi-subtrip trips are of the greatest concern. These are the trips having the potential to fish on multiple stocks of fish in a single trip and where misreporting of statistical area(s) may lead to incorrect estimates of stock removals. For each trip, the levels of agreement between the NEFOP, VMS and VTR statistical areas were categorized as in agreement (‘Yes’), not in agreement (‘No’) or in partial agreement (‘Partial’, at least one statistical area was in agreement, but not all). Agreement levels were contingent on agreement among both the number of statistical areas reported and the identity of those statistical areas. For example, if a VTR reports that fishing occurred in statistical areas 515 and 521 and VMS positions indicate that fishing occurred in 515 and 521 then the trip would be considered to be in agreement (‘Yes’). If the VTR reported fishing in 515, and the VMS data suggests fishing occurred in 515 and 521, then the trip would be considered to be in partial agreement (‘Partial’). If the VTR reported fishing in 515, and the VMS data suggests fishing occurred only in 521, then the trip would not be considered to be in agreement (‘No’). The same analysis was also done on the larger set of VMS and VTR matched trips.

A VMS-based allocation algorithm was devised using the statistical areas fished from the VMS data to re-allocate VTR-reported landings to stock area. Fishing activity was assigned to stock area based on the species landed and statistical area in which the fishing activity was occurring. The time spent fishing in each stock area was estimated as the sum of fishing activity blocks occurring in each stock area (the duration of one activity block is contingent on the VMS polling frequency which is variable, but generally once per 30 minutes for scallop vessels and once per hour for groundfish vessels). Total VTR trip landings for each species (*s*) were allocated to stock area (*k*) based on the ratio of time spent fishing in each stock area as determined from VMS locations (Equation 1).

$$(1) \qquad \hat{L}_{sk} = \left(\left(\sum l_{si}\right) + l_{sk}\right) \bullet \left(\frac{t_k}{\left(\sum t_i\right) + t_k}\right)$$

where:

$\hat{L}_{sk}$ = VMS prorated trip landings for species *s*, stock *k* (kg)

l_s = trip landings for species *s* in stock area, *k*, as derived from VTR reports (kg)

l_i = trip landings for species *s* in stock areas *i*, where $i \neq k$, as derived from VTR reports (kg)

t_k = time spent fishing in stock area, *k*, as derived from VMS positional data (days)

t_i = time spent fishing in stock area *i*, where $i \neq k$, as derived form VMS positional data (days)

The results of the VMS-based allocation were compared to landings allocation derived from both NEFOP and VTR data sources to assess the relative accuracy of the VTR-based allocation and determine if the VMS-based algorithm resulted in improved estimates of landings by stock area. VTR and NEFOP species landings were prorated by assigning landings to stock area based on the reported statistical area. All comparisons were performed through examination of percent allocation to stock area as opposed to absolute landings because percent allocations derived from the traditional VTR source are used to allocate the amounts of commercial landings as determined through dealer weighout data (Wigley et al., 1998). The same analysis was performed on the larger VMS-VTR matched data set.

The VMS-based allocation method assumes a constant species catch-per-unit-effort (CPUE) at all fishing locations (i.e., species catch is distributed only as a function of the time spent fishing in each stock area). This assumption neglects species habitat preferences (e.g., sediment composition, water depth and temperature, etc.) which would result in species being more likely to be caught in some locales and not others. To assess the degree to which this assumption was violated, individual species trip allocations from the VMS-method were compared to the same allocations as determined from NEFOP observations using linear regression.

Results

Method validation using NEFOP data

Statistical area agreement between NEFOP and VTR was > 94 % for single subtrip trips across all years, but < 17 % for multi-subtrips (Table 4). Nearly all disagreements among the 'partial' multi-subtrip trips matches (> 98 %) are due to under-reporting of statistical areas (fewer statistical areas reported on the VTR compared to NEFOP); 105 trips in 2004, 337 in 2005 and 166 in 2006. There was a general trend towards improved VTR reporting of multi-subtrip trips over time, however given the small sample size and potential for observer-type effects on VTR-reporting, such a conclusion may be premature. The statistical area agreement between NEFOP and VMS-based statistical areas was lower (≥ 88.0 %) for single-subtrip trips compared to the NEFOP-VTR comparisons (Table 5). The cause of disagreement among single-subtrip trips is due to the overestimation of statistical areas fished by the VMS-based method. The overestimation results from the VMS-based method misclassifying non-fishing activity as fishing activity. Agreement among multi-subtrip trips is greater (> 67 %) when using the VMS-method compared to the VTR-reported statistical area trips, with no complete disagreement among any of the trips. Among statistical areas in partial agreement there was a tendency for the VMS-method to overestimate the number of statistical areas fished (59.5 % of partial matches in 2004, 53.3 % in 2005 and 50.8 % in 2006). The performance of the VMS-based method in detecting statistical areas fished is not equivalent for all gear types; a closer examination of the VMS-NEFOP statistical area comparison in 2005 showed that 80.3 % (535 of 666) of trawl trips, 65.4 % (17 of 26) of dredge trips, 83.8 % (88 of 105) of gillnet trips and 97.1 % (101 of 104) of longline trips have agreement levels of 'Yes'. This finding supports the assumption that the misclassification of the location of fixed gear fishing activity is less likely compared to mobile gear activity.

The VMS-based allocation method arrived at annual stock allocations closer to NEFOP allocations relative to VTR allocations for 18 of the 24 comparisons examined (eight species over three years) (Tables 6 – 8). There were no species allocations for which the VMS-based allocation under-performed the VTR allocation in all three years; haddock was the only species for which the VMS-based allocation under-performed in two of the three years. There was general improvement in the VMS-based allocation over time with the number of species for which it under-performed the VTR allocation decreasing from three in 2004 to only one in 2006. Of all species, goosefish, silver hake and red hake had the greatest percent difference relative to the NEFOP allocation in all three years, with the single exception of windowpane flounder in 2004. It is important to consider the implications of the matched trip-set composition in the interpretation of these results; the performance of the VMS-based method is contingent on the number of multi-subtrip trips and the gear composition of the matched data set (i.e., a higher proportion of multi-subtrip trips would appear to improve performance and a higher proportion of dredge trips in the matched-set would appear to decrease performance). Comparisons of the individual trip stock allocations between the VMS-based method and NEFOP allocation showed strong agreement between VMS and NEFOP stock allocations ($r = 0.823$, $p < 0.001$, $n=514$; Fig. 5), however there was considerable spread in residuals.

Extrapolation to larger VMS-VTR matched dataset

The NEFOP-VMS-VTR subset of data used to validate the VMS-based method is relatively small compared to the total population of VTR-recorded trips (Table 3). The validation results suggest that for some trips monitored through VMS, the VMS-based allocation method can be used to gauge the accuracy of the stock allocations as determined through VTR reports. The VMS-VTR matched set is a much larger dataset. The subset of VTR reports examined (eight species caught using the four gear types) account for only approximately a quarter of the total VTR reports in a given year (Table 3), however this dataset accounts for > 96 % of the landings of all the study species across the time series (Table 9). Similarly, VMS coverage is available for only 5,892 to 19,165 of the VTR trips in a given year (Table 3), but these trips account for 17.6 to 92.0 % of the total landings of individual species (Table 9). By 2006, VMS data were available for trips responsible for landing > 70 % of all species but goosefish; coverage of goosefish landings is low because there are no specific VMS requirements for the goosefish fishery (Table 2). All demersal species examined are primarily caught by the otter trawl fishery except goosefish where gillnet gear is responsible for the majority of the landings. Gillnet is the secondary gear type for all species with the exception of haddock and silver hake which are secondarily targeted by benthic longline (Tables 10 -12). VMS coverage of the landings by most gear types is highly variable, though generally increasing with time; there is a general pattern of low gillnet coverage for landings of most species across time.

Examination of the VTR statistical area reporting using VMS-based statistical areas fished showed similar patterns to those observed in the NEFOP-VMS-VTR comparisons. Agreement levels of single-subtrip trips exceeded 92 % in all years and was always < 6.5 % for multi-subtrip trips (Table 13). These are lower agreement levels for the multi-subtrip trips than observed in the NEFOP-VTR comparison; it is unclear whether these lower rates of agreement are due to the overestimation of the number of statistical areas fished by the VMS method or an observer-effect that would have resulted in improved VTR reporting of multiple-subtrip trips when observers were on board, or some other factor. Closer examination of the partial matches revealed that the number of vessels apparently under-reporting the number of statistical areas fished was 397 in 2004, 477 in 2005 and 629 in 2006. Those vessels that likely frequently under-report trips (> 5 trips in a year) are responsible for the majority of the potentially under-reported trips. In 2004 there were 179 vessels that appeared to frequently under-report. These vessels accounted for 1,876 of 2,797 of partial agreement trips (67.1 %). In 2005, there were 221 vessels in this category; they accounted for 2,787 of the 3,837 partial agreement trips (72.6 %) and in 2006 there were 268 vessels which potentially submitted > 5 under-reported trips accounting for 3,815 of the 5,251 partial agreement trips (72.7 %).

Because the performance of the VMS algorithm is sensitive to the number of multi-stock trips taken in a given year it is important to understand the types of trips recorded in the VMS dataset and how that composition varies over time. The percentage of multi-stock trips recorded by VMS increased in 2005 followed by a decline in 2006 to levels below 2004 values for all but windowpane, silver hake and red hake trips (Table 14). Those trips fishing on multiple stocks are predominantly (≥ 99.0 %) mobile-gear vessels (Table 15), implying that fixed-gear fishing effort occurs primarily in localized geographic areas such that landings from fixed-gear trips are unlikely to have come from multiple stocks. This supports the prior assumption that the misinterpretation of the VMS speed signals from fixed-gear trips is unlikely to result in the misallocation of landings.

The perceived under-reporting of statistical areas in the VTR data led to minor (< 5 %) differences in the overall stock allocations; only two stocks in the three year time-series exhibited differences in stock allocations exceeding 2.0 % (2004 silver hake, ± 3.0 %; and 2006 windowpane flounder, ± 4.7 %; Tables 16 – 18). These figures are similar to the total proportion of species landings potentially misallocated, which was < 5 % for all species-years examined; again with the exception of 2004 silver hake and 2006 windowpane flounder. However, these small differences in percent allocation have a disproportionate effect on the less abundant stock such as such as Gulf of Maine haddock, southern New England yellowtail, southern windowpane and northern silver hake. For these, stocks, minor differences can be large (≥ 5.0 %) relative to the percent of the total species landings allocated to that stock (Tables 16-18). These impacts are most notable in the stock allocations of the southern New England/mid-Atlantic yellowtail flounder. Stock allocation differences between the VTR and VMS methods were ≤ 1.6 % for all years, however commercial landings of this stock were ≤ 6.4 % of the total stock landings as estimated from the VTR reports resulting in relative differences of 53.8, 61.9 and 25.0 % for the years 2004, 2005 and 2006 respectively. Of the 54 comparisons analyzed (8 species, 18 stocks, 3 years), the VMS-based method stock allocations had ≥ 5.0 % relative difference compared to the VTR-based allocations for 17 of the comparisons. Only southern New England/mid-Atlantic yellowtail, southern windowpane and northern silver hake exceeded the ≥ 5.0 % difference in all three years examined.

There was a tendency for the VTR-method to over-allocate the predominant Atlantic cod and haddock stocks (i.e., Georges Bank) with the exception of 2004 haddock. For yellowtail and winter flounder there was a tendency for the VTR-method to under allocate the predominant Georges Bank stock and over-allocate the Gulf of Maine and southern New England stocks. The only exception to this was 2005 winter flounder when there was a perceived under-allocation of VMS-based landings estimate of the southern New England stock. For all years, there was an over-allocation of landings to the southern goosefish stock using the VTR-method relative to the VMS method. The direction of stock allocation differences for windowpane flounder, silver hake and red hake was variable from year to year.

Discussion and Conclusions

The underreporting of statistical areas on VTR logbooks is a significant problem affecting > 80 % multi-subtrip trips. The VTR underreporting rates from this study agree closely with past studies that have used both NEFOP and haul-by-haul self reported data (Palmer et al., 2007). While the impacts of this underreporting are relatively small in regards to overall stock allocation percentages, the relative impacts on less abundant stocks such as southern New England/mid-Atlantic yellowtail can be significant. This is in agreement with the findings of other studies that have examined this issue using a smaller data set which utilized NEFOP-VTR comparisons (A. Applegate and T. Nies, NEFMC, August 17, 2007, pers. comm.). These discrepancies have implications on the estimation of fishery removals and the assessment of these stocks. While the impacts are minimal for the majority of stocks examined, the extent of the impacts on those few stocks that are significantly affected suggests that this is a problem deserving of attention.

Many of the stock assessments of these eight species use finer stratification of commercial landings (e.g., quarter, market category, and gear groups) to construct the age-length keys used in virtual population analysis (VPA), or similar assessment models (Mayo and Terceiro, 2005). This paper does not consider the impacts of statistical area reporting patterns on these finer scale stratifications of commercial landings, however the accuracy of finer-scale allocations would be sensitive to the number of multi-subtrip trips included in each strata. It is possible that the effects of statistical area mis-reporting on stock allocations is reduced due to offsetting errors (i.e., a trip that misallocates 1,100 kg to the Georges Bank cod stock could be largely offset by a trip that misallocates 1,200 kg to the Gulf of Maine cod stock). However, the spatial accuracy of VTR reports is critical not only for the assessment of fish species, but also of protected species such as sea turtles (e.g., Murray, 2004, 2005, 2006; Orphanides and Bisak, 2006) and marine mammals (Belden et al., 2006). When these date are used at finer spatial scales the accuracy of VTR reports becomes increasingly important.

It is important to consider that the results of this study apply only to the trips monitored by VMS; however by 2006, trips responsible for > 70 % of multispecies landings were monitored by VMS (Table 9). VMS coverage of some fisheries such as the Northeast multispecies is nearing a census, with all vessels required to have a VMS unit installed when fishing under the Days-At-Sea (DAS) program (NEFMC, 2006). The increased coverage improves the utility of VMS data as a validation tool for managers and data set of spatial fishing patterns for analysts. The number of vessels responsible for the landings of the eight species examined has remained constant at slightly less than 1,200 (Table 3), however the number of these vessels monitored by VMS has increased from 38.5 % (453 of 1,176) to 76.7 % (886 of 1,155). The increase in VMS usage appears to have occurred primarily among the smaller-nearshore fleet in response to VMS requirements to participate in the general category scallop fishery (NEFMC, 2005) and the NE multispecies fishery (NEFMC, 2006) as indicated by the drop in percentage of multi-stock area trips recorded by VMS from 2004 to 2006 (Table 11). There was a decrease in the number of multiple stock area trips from 2005 to 2006 which may explain the greater degree of agreement between the VMS and VTR prorations in 2006 for Gulf of Maine cod, haddock and winter flounder.

The study results are sensitive to the accuracy of average VMS vessel-speeds in differentiating fishing activity from non-fishing activity and the validity of the VMS-based allocation. This study defines fishing activity using narrower speed ranges than have been used in past studies which should lead to more conservative estimates of fishing effort. The speed range used for the mobile gears agree closely with the speeds obtained from high-frequency polling of vessels GPS units suggesting that these ranges are reasonable. However, instantaneous vessels speeds are not collected by National Marine Fisheries Service's Northeast Region VMS Program, so this study relied on average vessel speeds. The averaging process blurs activity from observation to observation and results in speeds slower than actual speeds due to a corner-cutting effect (Deng et al., 2005; Palmer, 2007). These impacts were not considered in this study and represent an area of uncertainty. The speed ranges adequately classify fishing activity (> 98 % success for mobile gear), but tend to overestimate the amount of fishing by incorrectly classifying non-fishing effort as fishing (69.3 % misclassification of non-fishing scallop activity). The overestimation was apparent in the comparisons of statistical areas fished between VMS and NEFOP data (Table 5). VMS data indicate where it is likely that fishing effort is occurring but provide no information on catch composition; a critical assumption of the VMS-based allocation is that the proportion of species caught in across multiple stock areas on a fishing trip is only a function of the time spent fishing in each stock area. While the relationship between VMS and NEFOP allocations was significant, there was a considerable amount of variability (Fig. 5). This assumption is not independent of overestimation errors; disproportionate overestimation of time spent fishing in a particular stock area will have a direct affect on the VMS-based allocation.

The various uncertainties and shortcomings of the VMS allocation method point out that this is not a replacement for a VTR-based allocation. Additionally, the low vessel coverage of historical VMS data (Fig. 2) limits its use as a tool to correct historical mis-reporting. However, the results presented do show that VMS data can be used as a tool to monitor the accuracy and completeness of VTRs and guide efforts to improve VTR compliance. The number of vessels which are potentially under-reporting statistical areas on a frequent basis is small (< 250 vessels) relative to the total number of vessels submitting VTRs (> 2,400; Table 3). The study results show that there is a need to improve compliance of VTR reporting regulations, particularly among those vessels likely to be fishing on multiple fish stocks. Given the manageable size of the problem and availability of tools to monitor these data, the quality of self-reported data should be monitored and improved through targeted outreach and education activities.

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Tables

Table 1. Statistical areas used to define species stock units for eight species examined.

Species	Stock area	Statistical areas
Atlantic cod *(Gadus morhua)*	Georges Bank (GBK)	521, 522, 525, 526, 533, 534, 537 - 539, 541 - 543, 551, 552, 561, 562, 611 - 616, 621 - 629, 631 - 639
	Gulf of Maine (GOM)	464, 465, 511 - 515
Haddock *(Melanogrammus aeglefinus)*	Georges Bank (GBK)	521, 522, 525, 526, 533, 534, 537 - 539, 541 - 543, 551, 552, 561, 562, 611 - 616, 621 - 629, 631 - 639
	Gulf of Maine (GOM)	464, 465, 511 - 515
Yellowtail flounder *(Limanda ferruginea)*	Georges Bank (GBK)	522, 525, 551, 552, 561, 562
	Cape Cod/Gulf of Maine (GOM)	464, 465, 511, 512, 513, 514, 515, 521
	Southern New England/ Mid-Atlantic (SNE)	526, 533, 534, 537 - 539, 541 - 543, 611 - 616, 621 - 629, 631 - 639
Winter flounder *(Pseudopleuronectes americanus)*	Georges Bank (GBK)	522, 525, 551, 552, 561, 562
	Gulf of Maine (GOM)	464, 465, 511, 512, 513, 514, 515
	Southern New England/ Mid-Atlantic (SNE)	521, 526, 533, 534, 537 - 539, 541 - 543, 611 - 616, 621 - 629, 631 - 639
Windowpane flounder *(Scophthalmus aquosus)*	North (NOR)	464, 465, 511 - 515, 521, 522, 525, 542, 543, 551, 552, 561, 562
	South (SOU)	526, 533, 534, 537 - 539, 541, 611 - 616, 621 - 629, 631 - 639
Goosefish *(Lophius americanus)*	North (NOR)	464, 465, 511 - 515, 521, 522, 551, 561
	South (SOU)	525, 526, 533, 534, 537 - 539, 541 - 543, 552, 562, 611 - 616, 621 - 629, 631 - 639
Silver hake *(Merluccius bilinearis)*	North (NOR)	464, 465, 511 - 515, 521, 522, 551, 561
	South (SOU)	525, 526, 533, 534, 537 - 539, 541 - 543, 552, 562, 611 - 616, 621 - 629, 631 - 639
Red hake *(Urophycis chuss)*	North (NOR)	464, 465, 511 - 515, 521, 522, 551, 561
	South (SOU)	525, 526, 533, 534, 537 - 539, 541 - 543, 552, 562, 611 - 616, 621 - 629, 631 - 639

Table 2. Fishery management plan (FMP) actions affecting VMS use over time in the northeast United States through December 31, 2006. **Note: if a vessel is subject to VMS regulations from multiple programs, the most restrictive regulation applies.*

Date effective	Fishery	Measure	Description	Reference
May 1998	Atlantic scallop	Amendment 4	Required VMS for all limited access full- and part-time vessels (hourly polling). **Note: Amendment 4 effective March 1994, but VMS implementation delayed by NMFS until May 1998.*	NEFMC, 1993
May 1999	Atlantic herring	Original FMP	Required VMS for all category 1 vessels (hourly polling).	NEFMC, 1999
May 2001	Atlantic scallop	Framework Adjustment 14	Required VMS for all limited access occasional-category vessels when participating in area access programs (half-hourly polling).	NEFMC, 2001
May 2004	Northeast multispecies	Amendment 13	Required VMS for all vessels accessing the US/Canada shared resource area (half-hour polling within US/Canada area, hourly polling outside).	NEFMC, 2003
November 2004	Atlantic scallop	Framework Adjustment 16	Required VMS for all general category vessels participating in area access programs (half-hour polling).	NEFMC, 2004a
November 2004	Northeast multispecies	Framework Adjustment 40A	Required VMS for all vessels participating in special access programs (SAP) and when fishing under the Regular B Days-at-Sea (DAS) Program (hourly polling).	NEFMC, 2004b
October 2005	Atlantic scallop	Framework Adjustment 17	Required VMS for all general category vessels landing > 40 lb scallop meats (half-hour polling).	NEFMC, 2005
November 2006	Northeast multispecies	Framework Adjustment 42	Required VMS for all limited access NE multispecies DAS vessels using groundfish DAS (hourly polling).	NEFMC, 2006

Table 3. Summary of the data sets used, by number of trips and number of vessels, from 2004 to 2006.

Year	Category	Number of trips	Number of Vessels
2004	VTR dataset	114,491	2,629
	VTR subset	32,272	1,176
	VMS-VTR matched set	5,892	453
	NEFOP-VMS-VTR matched set	249	150
2005	VTR dataset	121,442	2,599
	VTR subset	33,090	1,161
	VMS-VTR matched set	9,909	622
	NEFOP-VMS-VTR matched set	901	252
2006	VTR dataset	118,548	2,497
	VTR subset	32,431	1,155
	VMS-VTR matched set	19,165	886
	NEFOP-VMS-VTR matched set	514	255

Table 4. Summary of the agreement levels between statistical areas fished recorded by NEFOP and the statistical areas fished reported on VTRs from matched fishing trips from 2004 to 2006. Trip subcategories are based on the NEFOP-reported number of statistical areas fished. **Note: percentages may not sum to 100 due to rounding.*

Year	Subtrip category	Subtrip category trips	Agreement level	Number of trips	Percent of total subtrip trips (%)
2004	Single subtrip	135	Yes	129	95.6
			No	6	4.4
	Multi-subtrip	114	Yes	6	5.3
			No	2	1.8
			Partial	106	93.0
2005	Single subtrip	490	Yes	462	94.3
			No	27	5.5
			Partial	1	0.2
	Multi-subtrip	411	Yes	57	13.9
			No	13	3.2
			Partial	341	83.0
2006	Single subtrip	305	Yes	293	96.1
			No	10	3.3
			Partial	2	0.7
	Multi-subtrip	209	Yes	35	16.7
			No	6	2.9
			Partial	168	80.4

Table 5. Summary of the agreement levels between statistical areas fished recorded by NEFOP and the statistical areas fished as determined using VMS positional data from matched fishing trips from 2004 to 2006. Trip subcategories are based on the NEFOP-reported number of statistical areas fished. **Note: percentages may not sum to 100 due to rounding.*

Year	Subtrip category	Subtrip category trips	Agreement level	Number of trips	Percent of total subtrip trips (%)
2004	Single subtrip	135	Yes	123	91.1
			Partial	12	8.9
	Multi-subtrip	114	Yes	77	67.5
			Partial	37	32.5
2005	Single subtrip	490	Yes	431	88.0
			No	1	0.2
			Partial	58	11.8
	Multi-subtrip	411	Yes	306	74.5
			Partial	105	25.5
2006	Single subtrip	306	Yes	274	89.5
			Partial	32	10.5
	Multi-subtrip	208	Yes	149	71.6
			Partial	59	28.4

Table 6. Comparison of NEFOP, VTR and VMS stock allocation of 2004 commercial landings based on 249 matched trips. Bold text is used to indicate which method, VTR or VMS, achieve results closest to NEFOP allocations. **Note: percentages may not sum to 100 due to rounding.*

Species	Total Observer species landings (kg)	Total VTR species landings (kg)	Stock area	NEFOP landings allocation (kg)	VTR landings allocation (kg)	VMS landings allocation (kg)	NEFOP stock allocation (%)	VTR stock allocation (%)	*VTR difference (%)*	VMS stock allocation (%)	*VMS difference (%)*
Atlantic cod *(Gadus morhua)*	134,732	121,281	GBK	121,143	110,140	109,975	89.9	90.8	-0.9	**90.7**	**-0.8**
			GOM	13,588	11,141	11,306	10.1	9.2	0.9	**9.3**	**0.8**
Haddock *(Melanogrammus aeglefinus)*	507,806	501,287	GBK	499,955	493,985	494,177	98.5	**98.5**	**-0.1**	98.6	-0.1
			GOM	7,851	7,302	7,110	1.5	**1.5**	**0.1**	1.4	0.1
Yellowtail flounder *(Limanda ferruginea)*	252,865	281,582	GBK	247,173	271,682	274,809	97.7	96.5	1.3	**97.6**	**0.2**
			GOM	5,582	9,900	6,684	2.2	3.5	-1.3	**2.4**	**-0.2**
			SNE	109		88	0.0	0.0	0.0	**0.0**	**0.0**
Winter flounder *(Pseudopleuronectes americanus)*	170,741	203,914	GBK	152,184	168,733	184,100	89.1	82.7	6.4	**90.3**	**-1.2**
			GOM	5,362	4,452	4,727	3.1	2.2	1.0	**2.3**	**0.8**
			SNE	13,194	30,729	15,087	7.7	15.1	-7.3	**7.4**	**0.3**
Windowpane flounder *(Scophthalmus aquosus)*	153	66	NOR	144	66	42	94.4	**100.0**	**-5.6**	64.3	30.0
			SOU	9		23	5.6	**0.0**	**5.6**	35.7	-30.0
Goosefish *(Lophius americanus)*	380,531	71,311	NOR	335,799	54,720	55,942	88.2	76.7	11.5	**78.4**	**9.8**
			SOU	44,732	16,591	15,369	11.8	23.3	-11.5	**21.6**	**-9.8**
Silver hake *(Merluccius bilnearis)*	24,840	23,280	NOR	4,614	3,685	5,031	18.6	**15.8**	**2.7**	21.6	-3.0
			SOU	20,226	19,595	18,250	81.4	**84.2**	**-2.7**	78.4	3.0
Red hake *(Urophycis chuss)*	2,869	2,655	NOR	1,252	797	850	43.6	30.0	13.6	**32.0**	**11.6**
			SOU	1,617	1,858	1,805	56.4	70.0	-13.6	**68.0**	**-11.6**

Table 7. Comparison of NEFOP, VTR and VMS stock allocation of 2005 commercial landings based on 901 matched trips. Bold text is used to indicate which method, VTR or VMS, achieve results closest to NEFOP allocations. **Note: percentages may not sum to 100 due to rounding.*

Species	Total Observer species landings (kg)	Total VTR species landings (kg)	Stock area	NEFOP landings allocation (kg)	VTR landings allocation (kg)	VMS landings allocation (kg)	NEFOP stock allocation (%)	VTR stock allocation (%)	*VTR difference (%)*	VMS stock allocation (%)	*VMS difference (%)*
Atlantic cod *(Gadus morhua)*	653,066	593,995	GBK	599,457	545,989	541,523	91.8	**91.9**	**-0.1**	91.2	0.6
			GOM	53,609	48,006	52,472	8.2	**8.1**	**0.1**	8.8	-0.6
Haddock *(Melanogrammus aeglefinus)*	1,456,503	1,481,989	GBK	1,431,364	1,440,899	1,433,354	98.3	**97.2**	**1.0**	96.7	1.6
			GOM	25,139	41,090	48,635	1.7	**2.8**	**-1.0**	3.3	-1.6
Yellowtail flounder *(Limanda ferruginea)*	780,959	817,279	GBK	758,539	773,181	791,561	97.1	94.6	2.5	**96.9**	**0.3**
			GOM	21,652	23,010	24,687	2.8	2.8	0.0	**3.0**	**-0.2**
			SNE	768	21,088	1,030	0.1	2.6	-2.5	**0.1**	**0.0**
Winter flounder *(Pseudopleuronectes americanus)*	548,666	640,737	GBK	463,772	520,883	534,598	84.5	81.3	3.2	**83.4**	**1.1**
			GOM	9,403	26,073	8,308	1.7	4.1	-2.4	**1.3**	**0.4**
			SNE	75,491	93,781	97,831	13.8	14.6	-0.9	**15.3**	**-1.5**
Windowpane flounder *(Scophthalmus aquosus)*	16,477	13,851	NOR	16,460	13,398	13,780	99.9	96.7	3.2	**99.5**	**0.4**
			SOU	16	454	71	0.1	3.3	-3.2	**0.5**	**-0.4**
Goosefish *(Lophius americanus)*	1,277,812	268,890	NOR	898,895	166,563	172,457	70.3	61.9	8.4	**64.1**	**6.2**
			SOU	378,917	102,327	96,433	29.7	38.1	-8.4	**35.9**	**-6.2**
Silver hake *(Merluccius bilnearis)*	75,370	72,752	NOR	23,266	26,305	26,140	30.9	36.2	-5.3	**35.9**	**-5.1**
			SOU	52,104	46,447	46,612	69.1	63.8	5.3	**64.1**	**5.1**
Red hake *(Urophycis chuss)*	4,165	3,877	NOR	3,139	2,592	2,769	75.4	66.9	8.5	**71.4**	**3.9**
			SOU	1,025	1,285	1,107	24.6	33.1	-8.5	**28.6**	**-3.9**

Table 8. Comparison of NEFOP, VTR and VMS stock allocation of 2006 commercial landings based on 514 matched trips. Bold text is used to indicate which method, VTR or VMS, achieve results closest to NEFOP allocations. **Note: percentages may not sum to 100 due to rounding.*

Species	Total Observer species landings (kg)	Total VTR species landings (kg)	Stock area	NEFOP landings allocation (kg)	VTR landings allocation (kg)	VMS landings allocation (kg)	NEFOP stock allocation (%)	VTR stock allocation (%)	*VTR difference (%)*	VMS stock allocation (%)	*VMS difference (%)*
Atlantic cod *(Gadus morhua)*	234,013	207,562	GBK	201,266	176,561	177,335	86.0	85.1	0.9	**85.4**	**0.6**
			GOM	32,747	31,001	30,227	14.0	14.9	-0.9	**14.6**	**-0.6**
Haddock *(Melanogrammus aeglefinus)*	312,195	286,961	GBK	304,139	268,746	275,605	97.4	93.7	3.8	**96.0**	**1.4**
			GOM	8,056	18,215	11,356	2.6	6.3	-3.8	**4.0**	**-1.4**
Yellowtail flounder *(Limanda ferruginea)*	270,492	288,175	GBK	256,683	277,142	275,958	94.9	96.2	-1.3	**95.8**	**-0.9**
			GOM	12,548	10,029	10,530	4.6	3.5	1.2	**3.7**	**1.0**
			SNE	1,261	1,004	1,686	0.5	0.3	0.1	**0.6**	**-0.1**
Winter flounder *(Pseudopleuronectes americanus)*	193,511	202,203	GBK	165,082	168,158	171,834	85.3	83.2	2.1	**85.0**	**0.3**
			GOM	3,109	2,827	2,834	1.6	1.4	0.2	**1.4**	**0.2**
			SNE	25,321	31,219	27,535	13.1	15.4	-2.4	**13.6**	**-0.5**
Windowpane flounder *(Scophthalmus aquosus)*	11,167	8,308	NOR	10,964	7,745	8,026	98.2	93.2	5.0	**96.6**	**1.6**
			SOU	204	563	282	1.8	6.8	-5.0	**3.4**	**-1.6**
Goosefish *(Lophius americanus)*	697,289	150,874	NOR	450,096	105,992	110,857	64.5	**70.3**	**-5.7**	73.5	-8.9
			SOU	247,193	44,883	40,017	35.5	**29.7**	**5.7**	26.5	8.9
Silver hake *(Merluccius bilnearis)*	67,997	57,500	NOR	30,157	23,221	23,584	44.4	40.4	4.0	**41.0**	**3.3**
			SOU	37,840	34,278	33,916	55.6	59.6	-4.0	**59.0**	**-3.3**
Red hake *(Urophycis chuss)*	5,318	4,354	NOR	3,888	2,908	3,328	73.1	66.8	6.3	**76.4**	**-3.3**
			SOU	1,431	1,447	1,027	26.9	33.2	-6.3	**23.6**	**3.3**

Table 9. Species-level summary of the data subsets compared to total VTR landings (kg) from 2004 to 2006.

Year	Species	Total VTR landings (kg)	VTR subset (kg)	Percent of total (%)	VMS matched set (kg)	Percent of total (%)
2004	Atlantic cod *(Gadus morhua)*	5,611,244	5,432,809	96.8	1,874,015	33.4
	Haddock *(Melanogrammus aeglefinus)*	6,919,871	6,837,521	98.8	5,096,088	73.6
	Yellowtail flounder *(Limanda ferruginea)*	6,954,627	6,899,760	99.2	5,378,986	77.3
	Winter flounder *(Pseudopleuronectes americanus)*	4,515,996	4,483,488	99.3	3,127,780	69.3
	Windowpane flounder *(Scophthalmus aquosus)*	92,640	91,522	98.8	18,217	19.7
	Goosefish *(Lophius americanus)*	7,561,854	7,440,979	98.4	1,332,178	17.6
	Silver hake *(Merluccius bilinearis)*	7,454,395	7,392,633	99.2	2,071,931	27.8
	Red hake *(Urophycis chuss)*	875,228	863,357	98.6	236,830	27.1
2005	Atlantic cod *(Gadus morhua)*	5,072,510	4,983,113	98.2	2,754,687	54.3
	Haddock *(Melanogrammus aeglefinus)*	6,198,222	6,155,937	99.3	5,700,737	92.0
	Yellowtail flounder *(Limanda ferruginea)*	3,925,078	3,922,078	99.9	3,475,993	88.6
	Winter flounder *(Pseudopleuronectes americanus)*	3,473,132	3,457,729	99.6	2,800,639	80.6
	Windowpane flounder *(Scophthalmus aquosus)*	81,693	81,532	99.8	45,771	56.0
	Goosefish *(Lophius americanus)*	7,377,131	7,259,875	98.4	2,129,989	28.9
	Silver hake *(Merluccius bilinearis)*	7,526,280	7,522,877	99.9	3,531,069	46.9
	Red hake *(Urophycis chuss)*	549,641	547,200	99.6	154,666	28.1
2006	Atlantic cod *(Gadus morhua)*	4,623,801	4,546,055	98.3	3,428,790	74.2
	Haddock *(Melanogrammus aeglefinus)*	2,810,657	2,713,290	96.5	2,513,767	89.4
	Yellowtail flounder *(Limanda ferruginea)*	1,891,367	1,867,650	98.7	1,681,115	88.9
	Winter flounder *(Pseudopleuronectes americanus)*	2,589,643	2,583,503	99.8	2,128,052	82.2
	Windowpane flounder *(Scophthalmus aquosus)*	87,187	87,012	99.8	61,654	70.7
	Goosefish *(Lophius americanus)*	6,109,614	6,026,365	98.6	3,246,832	53.1
	Silver hake *(Merluccius bilinearis)*	5,331,664	5,327,921	99.9	4,606,490	86.4
	Red hake *(Urophycis chuss)*	559,679	553,489	98.9	458,731	82.0

Table 10. 2004 summary of the VMS data subsets compared to the subset of VTR landings (kg), by species and gear type.

Species	VTR gear code	VTR			VMS			
		Number of Vessels	**Number of trips**	**VTR landings (kg)**	**Number of Vessels**	**Number of trips**	**VMS landings (kg)**	**Percent of VTR landings (%)**
Atlantic cod *(Gadus morhua)*	OTF	444	9,167	3,507,919	189	2,724	1,829,688	52.2
	DRS	6	9	535	3	3	14	2.5
	GNS	171	6,972	1,726,238	4	116	25,959	1.5
	LLB	67	1,221	198,117	21	253	18,355	9.3
Haddock *(Melanogrammus aeglefinus)*	OTF	384	6,323	5,908,548	187	2,472	4,619,014	78.2
	DRS	1	1	0	0	0	0	*N/A*
	GNS	137	3,313	133,401	3	86	9,789	7.3
	LLB	55	986	795,572	21	261	467,285	58.7
Yellowtail flounder *(Limanda ferruginea)*	OTF	404	7,337	6,749,688	181	2,061	5,373,053	79.6
	DRS	36	62	4,346	33	48	4,072	93.7
	GNS	93	1,541	145,727	2	31	1,862	1.3
	LLB	0	0	0	0	0	0	*N/A*
Winter flounder *(Pseudopleuronectes americanus)*	OTF	471	9,866	4,393,835	184	2,314	3,125,651	71.1
	DRS	18	37	750	16	26	660	87.9
	GNS	129	3,029	88,606	2	57	1,433	1.6
	LLB	9	67	298	2	10	37	12.3
Windowpane flounder *(Scophthalmus aquosus)*	OTF	158	1,291	90,880	46	105	18,217	20.0
	DRS	0	0	0	0	0	0	*N/A*
	GNS	12	63	642	0	0	0	0.0
	LLB	0	0	0	0	0	0	*N/A*
Goosefish *(Lophius americanus)*	OTF	555	9,467	1,870,948	208	2,325	880,759	47.1
	DRS	226	1,226	381,761	214	1,179	380,203	99.6
	GNS	268	8,119	5,186,982	4	118	70,362	1.4
	LLB	26	146	1,288	16	75	854	66.3
Silver hake *(Merluccius bilinearis)*	OTF	234	3,212	7,334,373	68	721	2,069,807	28.2
	DRS	0	0	0	0	0	0	*N/A*
	GNS	63	415	21,948	2	7	1,976	9.0
	LLB	4	17	36,311	2	4	148	0.4
Red hake *(Urophycis chuss)*	OTF	172	2,226	769,215	56	510	235,494	30.6
	DRS	0	0	0	0	0	0	*N/A*
	GNS	26	353	93,767	1	33	1,044	1.1
	LLB	7	21	376	3	7	292	77.6

Table 11. 2005 summary of the VMS data subsets compared to the subset of VTR landings (kg), by species and gear type.

Species	VTR gear code	VTR			VMS			
		Number of Vessels	Number of trips	VTR landings (kg)	Number of Vessels	Number of trips	VMS landings (kg)	Percent of VTR landings (%)
Atlantic cod *(Gadus morhua)*	OTF	381	9,005	3,201,456	229	4,415	2,491,742	77.8
	DRS	8	11	1,209	7	10	100	8.3
	GNS	157	6,711	1,574,496	21	697	164,299	10.4
	LLB	89	1,373	205,952	45	638	98,546	47.8
Haddock *(Melanogrammus aeglefinus)*	OTF	342	6,471	5,246,396	217	3,670	5,036,560	96
	DRS	3	4	15	2	3	14	93.9
	GNS	125	3,054	59,757	15	292	4,494	7.5
	LLB	80	1257	849,769	44	650	659,669	77.6
Yellowtail flounder *(Limanda ferruginea)*	OTF	352	7,138	3,815,235	218	3,175	3,473,828	91.1
	DRS	30	45	2,059	28	42	1,883	91.5
	GNS	77	1,180	104,756	5	30	259	0.2
	LLB	5	19	28	3	16	23	83.6
Winter flounder *(Pseudopleuronectes americanus)*	OTF	413	9,225	3,407,204	229	3,458	2,786,325	81.8
	DRS	37	65	13,237	36	64	12,772	96.5
	GNS	118	2,530	36,739	12	189	1,069	2.9
	LLB	11	84	549	6	66	473	86.1
Windowpane flounder *(Scophthalmus aquosus)*	OTF	158	1,057	80,999	78	227	45,762	56.5
	DRS	0	0	0	0	0	0	*N/A*
	GNS	9	77	523	0	0	0	0.0
	LLB	4	9	10	3	8	9	91.3
Goosefish *(Lophius americanus)*	OTF	493	9,197	1,857,280	260	3,603	1,359,021	73.2
	DRS	317	2,722	335,072	266	1,498	321,271	95.9
	GNS	246	8,736	5,065,683	34	801	448,437	8.9
	LLB	36	212	1,841	30	182	1,260	68.4
Silver hake *(Merluccius bilinearis)*	OTF	193	2,689	7,391,321	96	1197	3,489,085	47.2
	DRS	2	2	365	2	2	365	100.0
	GNS	41	255	20,219	1	8	4,400	21.8
	LLB	7	30	110,972	5	20	37,219	33.5
Red hake *(Urophycis chuss)*	OTF	143	1,838	482,879	69	757	152,655	31.6
	DRS	1	1	125	1	1	125	100.0
	GNS	24	239	64,020	2	25	1,810	2.8
	LLB	4	10	176	2	6	76	43.3

Table 12. 2006 summary of the VMS data subsets compared to the subset of VTR landings (kg), by species and gear type.

Species	VTR gear code	VTR			VMS			
		Number of Vessels	Number of trips	VTR landings (kg)	Number of Vessels	Number of trips	VMS landings (kg)	Percent of VTR landings (%)
Atlantic cod *(Gadus morhua)*	OTF	350	7,493	2,913,548	301	5,799	2,680,732	92.0
	DRS	5	8	420	4	7	184	43.8
	GNS	153	6,764	1,427,295	95	2739	656,843	46.0
	LLB	80	1,154	204,792	42	511	91,031	44.5
Haddock *(Melanogrammus aeglefinus)*	OTF	296	4,938	2,242,491	252	3,994	2,186,209	97.5
	DRS	5	5	1,303	4	4	1,299	99.7
	GNS	122	2,964	65,539	75	1275	26,864	41.0
	LLB	76	1091	403,958	42	496	299,395	74.1
Yellowtail flounder *(Limanda ferruginea)*	OTF	319	6,402	1,772,976	282	4,938	1,674,672	94.5
	DRS	24	36	4,098	23	35	4,076	99.4
	GNS	67	1,293	90,562	32	244	2,355	2.6
	LLB	5	12	14	4	11	13	96.7
Winter flounder *(Pseudopleuronectes americanus)*	OTF	381	8,460	2,534,691	310	5,530	2,115,716	83.5
	DRS	36	73	4,951	34	71	4,926	99.5
	GNS	109	2,825	43,398	64	979	6,983	16.1
	LLB	8	57	463	7	42	428	92.5
Windowpane flounder *(Scophthalmus aquosus)*	OTF	151	1,246	86,897	117	607	61,621	70.9
	DRS	1	2	7	1	2	7	100.0
	GNS	9	37	107	3	7	24	22.6
	LLB	1	1	2	1	1	2	100.0
Goosefish *(Lophius americanus)*	OTF	459	8,032	1,574,844	380	5,747	1,417,361	90.0
	DRS	336	3,917	323,214	333	3,650	317,777	98.3
	GNS	261	8,050	4,127,303	114	2910	1,510,988	36.6
	LLB	22	113	1,004	20	99	706	70.3
Silver hake *(Merluccius bilinearis)*	OTF	197	3,098	5,294,681	162	2242	4,590,130	86.7
	DRS	1	3	14	1	3	14	100.0
	GNS	37	251	18,600	22	98	11,729	63.1
	LLB	4	13	14,628	3	5	4,616	31.6
Red hake *(Urophycis chuss)*	OTF	152	1,983	525,546	119	1346	447,917	85.2
	DRS	2	2	29	2	2	29	100.0
	GNS	22	257	27,383	10	112	10,260	37.5
	LLB	4	6	531	3	5	524	98.7

Table 13. Summary of the agreement levels between statistical areas recorded on VTR reports and the statistical areas fished as determined using VMS positional data from matched fishing trips from 2004 to 2006. Trip subcategories are based on the VMS-determined number of statistical areas fished.*Note: percentages may not sum to 100 due to rounding.*

Year	Subtrip category	Subtrip category trips	Agreement level	Number of trips	Percent of total subtrip trips (%)
2004	Single subtrip	2,895	Yes	2,688	92.8
			No	194	6.7
			Partial	13	0.4
	Multi-subtrip	2,997	Yes	74	2.5
			No	139	4.6
			Partial	2,784	92.9
2005	Single subtrip	5,630	Yes	5,267	93.6
			No	334	5.9
			Partial	29	0.5
	Multi-subtrip	4,279	Yes	265	6.2
			No	206	4.8
			Partial	3,808	89.0
2006	Single subtrip	13,488	Yes	12,869	95.4
			No	590	4.4
			Partial	29	0.2
	Multi-subtrip	5,677	Yes	234	4.1
			No	221	3.9
			Partial	5,222	92.0

Table 14. Frequency of trips fishing on multiple stocks based on VMS data from 2004 to 2006.

Species	2004			2005			2006		
	Total trips	Multiple stock area trips	Percent (%)	Total trips	Multiple stock area trips	Percent (%)	Total trips	Multiple stock area trips	Percent (%)
Atlantic cod *(Gadus morhua)*	3,096	304	9.8	5,760	600	10.4	9,056	555	6.1
Haddock *(Melanogrammus aeglefinus)*	2,819	295	10.5	4,615	562	12.2	5,769	517	9.0
Yellowtail flounder *(Limanda ferruginea)*	2,140	186	8.7	3,263	352	10.8	5,228	367	7.0
Winter flounder *(Pseudopleuronectes americanus)*	2,407	286	11.9	3,777	604	16.0	6,622	453	6.8
Windowpane flounder *(Scophthalmus aquosus)*	105	19	18.1	236	24	10.2	617	28	4.5
Goosefish *(Lophius americanus)*	3,697	254	6.9	6,084	511	8.4	12,406	580	4.7
Silver hake *(Merluccius bilinearis)*	732	17	2.3	1,227	28	2.3	2,348	38	1.6
Red hake *(Urophycis chuss)*	550	9	1.6	789	8	1.0	1,465	23	1.6

Table 15. Frequency of fixed (GNS and LLB) or mobile (OTF and DRS) gear types used on trips fishing on multiple stocks based on VMS positional data from 2005.

Species	Number of total trips	Number of multiple stock area trips	Percent of total trips (%)	Gear category	Number of Trips	Percent of multiple stock area trips (%)
Atlantic cod *(Gadus morhua)*	5,760	600	10.4	Fixed	6	1.0
				Mobile	594	99.0
Haddock *(Melanogrammus aeglefinus)*	4,615	562	12.2	Fixed	4	0.7
				Mobile	558	99.3
Yellowtail flounder *(Limanda ferruginea)*	3,263	352	10.8	Fixed	0	0.0
				Mobile	352	100.0
Winter flounder *(Pseudopleuronectes americanus)*	3,777	604	16.0	Fixed	1	0.2
				Mobile	603	99.8
Windowpane flounder *(Scophthalmus aquosus)*	236	24	10.2	Fixed	0	0.0
				Mobile	24	100.0
Goosefish *(Lophius americanus)*	6,084	511	8.4	Fixed	0	0.0
				Mobile	511	100.0
Silver hake *(Merluccius bilinearis)*	1,227	28	2.3	Fixed	0	0.0
				Mobile	28	100.0
Red hake *(Urophycis chuss)*	789	8	1.0	Fixed	0	0.0
				Mobile	8	100.0

Table 16. Results of the VMS-based stock area allocation compared to the stock area allocation based on the VTR reported statistical area for 2004. Relative difference is determined at % difference/VTR stock allocation; differences ≥ 5.0 % are italicized. **Note: allocations may not sum to 100 due to rounding.*

Species	Total species landings (kg)	Stock area	VTR landings allocation (kg)	VMS landings allocation (kg)	Δ landings allocation abs(kg)	$\sum\Delta_i$/total species landings (%)	VTR stock allocation (%)	VMS Stock allocation (%)	Difference (%)	Relative difference (%)
Atlantic cod (*Gadus morhua*)	1,874,015	GBK	1,384,752	1,375,601	9,151	0.98	73.9	73.4	0.5	0.7
		GOM	489,263	498,414	9,151		26.1	26.6	-0.5	-1.9
Haddock (*Melanogrammus aeglefinus*)	5,096,088	GBK	4,763,038	4,806,095	43,057	1.69	93.5	94.3	-0.8	-0.9
		GOM	333,050	289,993	43,057		6.5	5.7	0.8	*12.3*
Yellowtail flounder (*Limanda ferruginea*)	5,378,987	GBK	5,094,590	5,176,798	82,208	3.06	94.7	96.2	-1.5	-1.6
		GOM	215,710	172,386	43,324		4.0	3.2	0.8	*20.0*
		SNE	68,687	29,802	38,885		1.3	0.6	0.7	*53.8*
Winter flounder (*Pseudopleuronectes americanus*)	3,127,781	GBK	2,420,182	2,459,208	39,026	2.59	77.4	78.6	-1.2	-1.6
		GOM	94,235	95,648	1,413		3.0	3.1	0.0	0.0
		SNE	613,364	572,925	40,439		19.6	18.3	1.3	*6.6*
Windowpane flounder (*Scophthalmus aquosus*)	18,217	NOR	16,807	16,725	82	0.90	92.3	91.8	0.5	0.5
		SOU	1,410	1,492	82		7.7	8.2	-0.5	*-6.5*
Goosefish (*Lophius americanus*)	1,332,178	NOR	787,572	801,448	13,876	2.08	59.1	60.2	-1.0	-1.7
		SOU	544,606	530,730	13,876		40.9	39.8	1.0	2.4
Silver hake (*Merluccius bilinearis*)	2,071,930	NOR	404,972	343,720	61,252	*5.91*	19.5	16.6	3.0	*15.4*
		SOU	1,666,958	1,728,210	61,252		80.5	83.4	-3.0	-3.7
Red hake (*Urophycis chuss*)	236,830	NOR	61,461	64,355	2,894	2.44	26.0	27.2	-1.2	-4.6
		SOU	175,369	172,475	2,894		74.0	72.8	1.2	1.6

Table 17. Results of the VMS-based stock area allocation compared to the stock area allocation based on the VTR-reported statistical area for 2005. Relative difference is determined at % difference/VTR stock allocation; allocations ≥ 5.0 % relative differences are italicized. **Note: allocations may not sum to 100 due to rounding.*

Species	Total species landings (kg)	Stock area	VTR landings allocation (kg)	VMS landings allocation (kg)	Δ landings allocation abs(kg)	$\sum\Delta_i$/total species landings (%)	VTR stock allocation (%)	VMS stock allocation (%)	Difference (%)	Relative difference (%)
Atlantic cod (*Gadus morhua*)	2,754,687	GBK	1,920,110	1,879,800	40,310	2.93	69.7	68.2	1.5	2.2
		GOM	834,577	874,887	40,310		30.3	31.8	-1.5	*-5.0*
Haddock (*Melanogrammus aeglefinus*)	5,700,737	GBK	5,319,329	5,285,374	33,955	1.19	93.3	92.7	0.6	0.6
		GOM	381,408	415,363	33,955		6.7	7.3	-0.6	*-9.0*
Yellowtail flounder (*Limanda ferruginea*)	3,475,993	GBK	3,115,140	3,164,191	49,051	2.82	89.6	91.0	-1.4	-1.6
		GOM	286,276	281,958	4,318		8.2	8.1	0.1	1.2
		SNE	74,577	29,844	44,733		2.1	0.9	1.3	*61.9*
Winter flounder (*Pseudopleuronectes americanus*)	2,800,638	GBK	1,976,251	1,985,963	9,712	1.39	70.6	70.9	-0.3	-0.4
		GOM	132,155	112,737	19,418		4.7	4.0	0.7	*14.9*
		SNE	692,232	701,939	9,707		24.7	25.1	-0.3	-1.2
Windowpane flounder (*Scophthalmus aquosus*)	45,772	NOR	43,740	44,337	597	2.61	95.6	96.9	-1.3	-1.4
		SOU	2,032	1,435	597		4.4	3.1	1.3	*29.5*
Goosefish (*Lophius americanus*)	2,129,989	NOR	1,188,433	1,223,924	35,491	3.33	55.8	57.5	-1.7	-3.0
		SOU	941,556	906,065	35,491		44.2	42.5	1.7	3.8
Silver hake (*Merluccius bilinearis*)	3,531,070	NOR	400,744	380,084	20,660	1.17	11.3	10.8	0.6	*5.3*
		SOU	3,130,326	3,150,986	20,660		88.7	89.2	-0.6	-0.7
Red hake (*Urophycis chuss*)	154,666	NOR	39,360	37,097	2,263	2.93	25.4	24.0	1.5	*5.9*
		SOU	115,306	117,569	2,263		74.6	76.0	-1.5	-2.0

Table 18. Results of the VMS-based stock area allocation compared to the stock area allocation based on the VTR-reported statistical area for 2006. Relative difference is determined at % difference/VTR stock allocation; allocations ≥ 5.0 % relative differences are italicized. **Note: allocations may not sum to 100 due to rounding.*

Species	Total species landings (kg)	Stock area	VTR landings allocation (kg)	VMS landings allocation (kg)	Δ landings allocation abs(kg)	$\sum\Delta_i$/total species landings (%)	VTR stock allocation (%)	VMS Stock allocation (%)	Difference (%)	Relative difference (%)
Atlantic cod (*Gadus morhua*)	3,428,790	GBK	2,012,366	2,009,838	2,528	0.15	58.7	58.6	0.1	0.2
		GOM	1,416,424	1,418,952	2,528		41.3	41.4	-0.1	-0.2
Haddock (*Melanogrammus aeglefinus*)	2,513,766	GBK	2,175,084	2,171,158	3,926	0.31	86.5	86.4	0.2	0.2
		GOM	338,682	342,608	3,926		13.5	13.6	-0.2	-1.5
Yellowtail flounder (*Limanda ferruginea*)	1,681,115	GBK	1,253,693	1,283,732	30,039	3.57	74.6	76.4	-1.8	-2.4
		GOM	319,177	315,714	3,463		19.0	18.8	0.2	1.1
		SNE	108,245	81,669	26,576		6.4	4.9	1.6	*25.0*
Winter flounder (*Pseudopleuronectes americanus*)	2,128,053	GBK	837,904	847,487	9,583	0.91	39.4	39.8	-0.5	-1.3
		GOM	151,351	151,497	146		7.1	7.1	0.0	0.0
		SNE	1,138,798	1,129,069	9,729		53.5	53.1	0.5	0.9
Windowpane flounder (*Scophthalmus aquosus*)	61,653	NOR	36,421	39,349	2,928	*9.50*	59.1	63.8	-4.7	*-8.0*
		SOU	25,232	22,305	2,927		40.9	36.2	4.7	*11.5*
Goosefish (*Lophius americanus*)	3,246,832	NOR	1,591,261	1,624,922	33,661	2.07	49.0	50.0	-1.0	-2.0
		SOU	1,655,571	1,621,910	33,661		51.0	50.0	1.0	2.0
Silver hake (*Merluccius bilinearis*)	4,606,490	NOR	876,514	950,975	74,461	3.23	19.0	20.6	-1.6	*-8.4*
		SOU	3,729,976	3,655,515	74,461		81.0	79.4	1.6	2.0
Red hake (*Urophycis chuss*)	458,731	NOR	142,190	145,968	3,778	1.65	31.0	31.8	-0.8	-2.6
		SOU	316,541	312,763	3,778		69.0	68.2	0.8	1.2

Figures

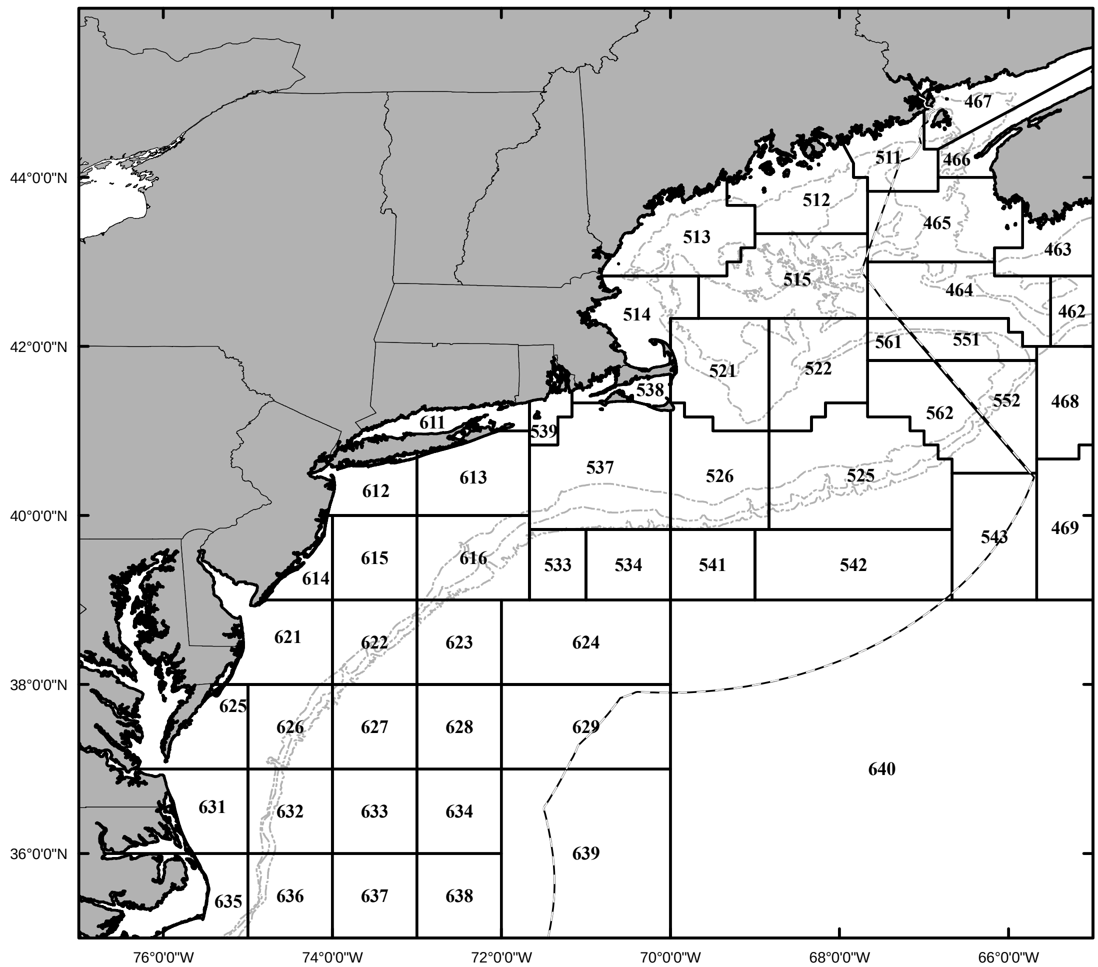

Figure 1. Statistical areas used for commercial fisheries data collection by the National Marine Fisheries Service in the Northeast Region. The 50, 100 and 500 fa bathymetric lines are shown in light gray and the U.S. Exclusive Economic Zone is indicated by the dashed black line.

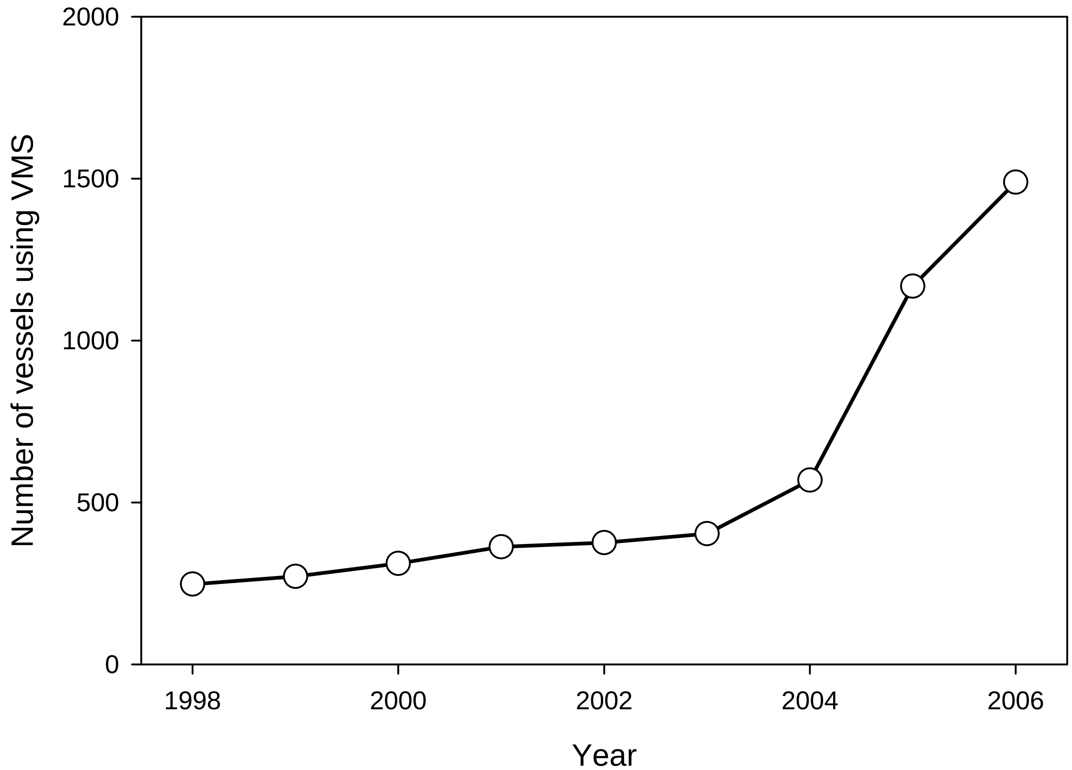

Figure 2. Number of vessels using VMS in the northeast United States between 1998 and 2006.

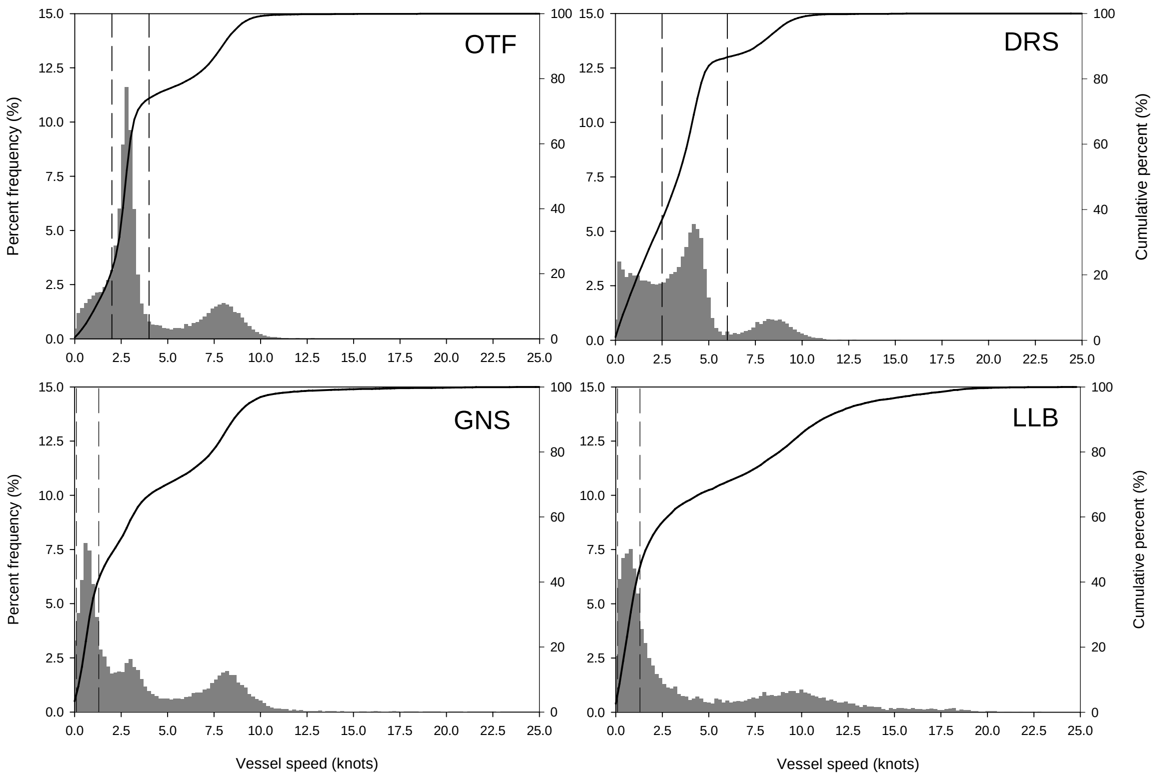

Figure 3. Percent frequency and cumulative percent distributions of average vessel speed (knots) as determined from VMS positions for vessels fishing fish bottom otter trawl (OTF), scallop dredge (DRS), sink gillnet (GNS) and benthic longline (LLB). The dashed lines represent the bounds used in this study to define fishing activity (OTF = 2.0 – 4.0 knots, DRS = 2.5 – 6.0 knots, GNS = 0.1 – 1.3 knots, LLB = 0.1 – 1.3 knots).

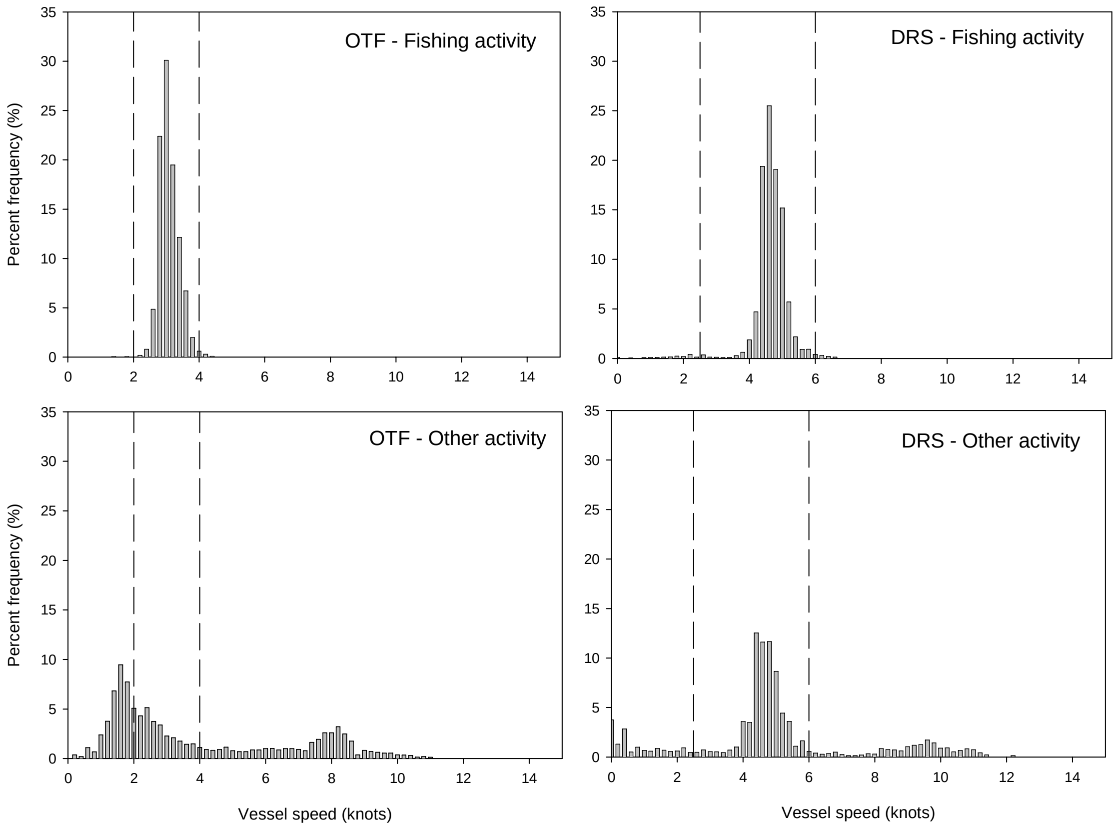

Figure 4. Percent frequency distribution of instantaneous vessel speed (knots) of vessels fishing fish bottom otter trawl gear (OTF) and scallop dredge gear (DRS) characterized by both ‘fishing’ and ‘other’ activity. These data were collected using high-frequency polling of the vessel’s GPS unit (1 observation/10 seconds) and represent the aggregate of two separate fishing trips taken by different vessels per gear type. The dashed lines represent the bounds used in this paper to define fishing activity (OTF = 2.0 – 4.0 knots, DRS = 2.5 – 6.0 knots).

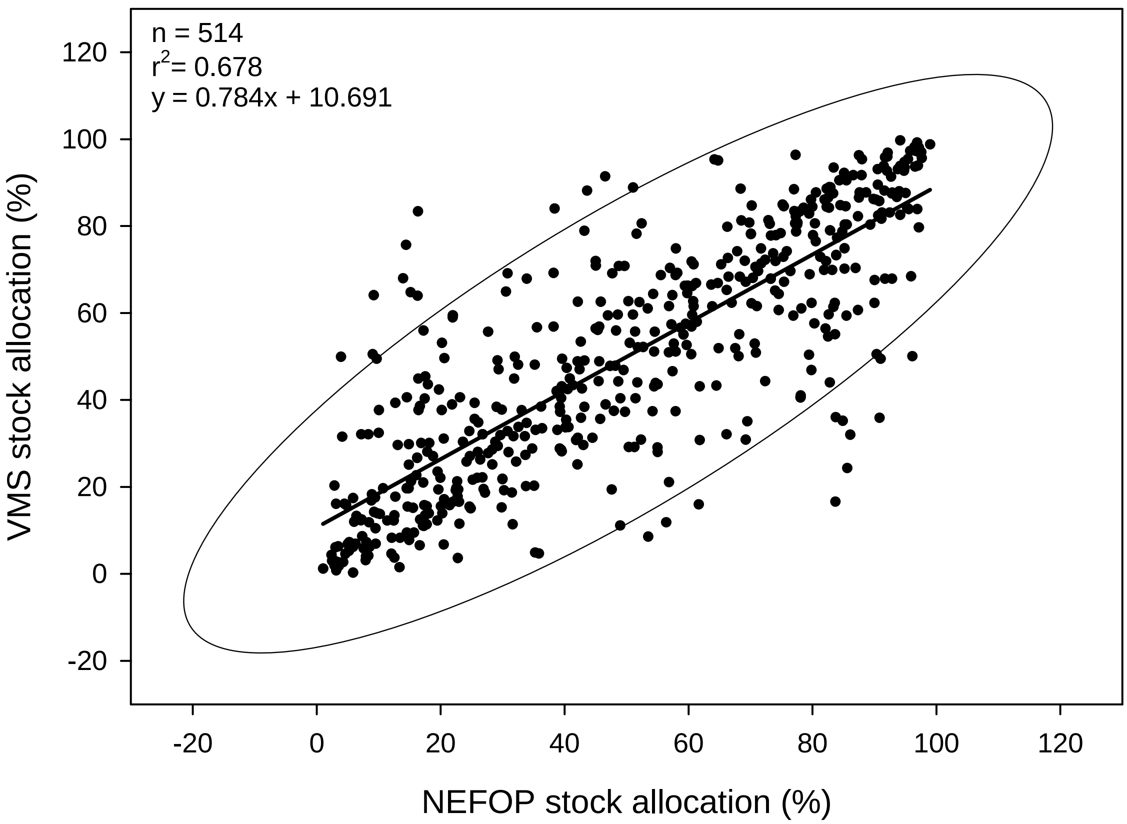

Figure 5. Comparison of 2005 VMS – NEFOP species stock allocations at the trip-level and associated 95 % confidence ellipse. Only those species-trip allocations where VMS and NEFOP-based methods agreed on the number of stock areas fished and the number of stock areas fished > 1 were compared.